Peel Force and Release Strength Behavior of a Peel Apart Dry Imaging Film

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Abstract

In this work we studied peel force and release strength as functions of temperature and pressure at short times in a peel apart dry imaging film system. It is observed that peel force F (which is the force required to separate a polymer layer and imaging layer containing carbon particles) increased with temperature as well as pressure. A theory based on wetting mechanism predicts a linear relationship for lnF vs. 1/T for short times at constant pressure. From this linear relation, the activation energy Ea of the system is obtained. The good agreement between the experimental data and the theoretical prediction suggests that primary adhesion mechanism for this interface at short times is due to the establishment of interfacial molecular contact by wetting. It is observed also that the release strength (which is a cohesive strength of the image supporting polymer composite layer on a PET substrate) increased with temperature and pressure. The effect of temperature on the release strength appears to illustrate a two-stage process: the first plateau may correspond to the attainment of complete wetting, and the second plateau to the attainment of equilibrium diffusion.

Introduction

Polaroid Helios is a peel apart, dry imaging film. The film basically consists of three coated layers, which is sandwiched between two polyester substrates (see Figure 1). Layer 1 is a thin light (or heat) sensitive polymer material (Tg = 96°C). Layer 2 is the imaging layer consisting of carbon particles embedded in a polymeric matrix. Layer 3 is release layer consisting of polymer composites, which coated on a polyester substrate.

High resolution Imaging is formed when an appropriate laser is focused at the interface between layer 1 and layer 2. An increase in adhesion strength is found at the site where the laser energy is absorbed. The exposed spot is revealed by physically separating the interface. At the site where the laser beam energy is absorbed, separation occurs within polymer composites of layer 3, which indicates a cohesive fracture in layer 3. On the other hand, at the area where no laser beam is applied, separation occurs at the interface between layer 1 and layer 2, which indicates a adhesive fracture. The result is a spot, or pixel element. Pixels of different gray values are constructed by increasing the numbers of pixel elements within the pixal area, or by removing the pixel elements.

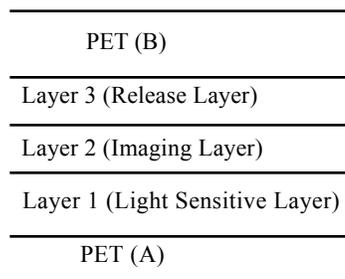| PET (B) |
|---|
| Layer 3 (Release Layer) |
| Layer 2 (Imaging Layer) |
| Layer 1 (Light Sensitive Layer) |
| PET (A) |

Figure 1. Helios dry imaging film structure.

Clearly, adhesive strength between layer 1 and layer 2 (defined as peel force), and cohesive strength of layer 3 (defined as release strength) have major impact on the image formation and quality. So far, a comprehensive understanding of the relationship between the structures and mechanical strengthes have not yet been established. Many different physical and chemical processes may occur simultaneously during laser bonding, including wetting, diffusion, chemisorption, crystalization, cross-linking, thermal degradation, and relaxation or build-up of internal stress. All can affect the adhesive and cohesive strengthes.

The object of this work is to study the adhesive and cohesive strengthes as function of temperature and pressure. Hopefully, this study will provide information for further understanding of the main structural features governing fracture mechanisms.

Experimental

The material used in this experiment was Polaroid Helios film. The Unit which controls temperature, pressure and contact time is a Talboy Laminator (Talboys Engineering Corp.). During the experiment, temperature varied from 240°F to 415°F and pressure applied were 60 psi and 70 psi. The contact time between rollers and sample was constant and short, about 0.06 sec.

At each temperature and pressure, a series of three 1×10 in^2 pieces of Helios film samples were put through the rollers. The samples then cut in half to make six 1×5 in^2 samples. These samples were stored at room temperature in air for 24 hours before peel force was measured on a peel tester (Instrumentors, Inc.).

Before proceeding, one important calculation is to estimate the interface temperature T from the heated roller temperature. A simple model for "a heated semi-infinite slab" can be used[1]. Assuming at time t = 0, the surface of

the PET (y=0) is suddenly rasied to heated roller temperature T_1 from room temperature T_0 due to initial lamination contact, and maintained at that temperature for contact time t > 0. One can find the time-dependent temperature profiles T(y, t) by following equation

$$\partial\Theta/\partial t = \alpha\ \partial^2\Theta/\partial y^2 \qquad (1)$$

where Θ is a dimensionless temperature $\Theta=(T-T_0)/(T_1-T_0)$. α is the thermal diffusivity of the film. With the initial and boundary conditions one can obtain following error function solution

$$\Theta = 1 - \text{erf}\ [y/(4\alpha t)^{1/2}] \qquad (2)$$

Error function is a well-known function and tables of it are readily available. In our case, the thickness of PET y≈44μm. PET thermal diffusivity $\alpha \approx 5.6 \times 10^{-4}$ cm^2/sec. The contact time between sample and heated roller t≈0.06 sec. Room temperature $T_0 \approx 25^{\circ}$C. Therefore, from equation (2), the interface temperature can be estimated.

(A) Study of the Peel Force

Theoretical

An important step in the formation of an adhesive bond is the establishment of interfacial molecular contact by wetting. The rate of wetting of interfacial void has been given as[2]

$$w = w_i\ [1 - a\ \exp(-t/b)]^{-2} \qquad (3)$$

where w is the size of the interfacial void at time t, w_i that at infinite time, and a and b are constants. Also, w can be expressed by following equation [1]

$$w = w_0\ (\ 1 - L_{12}/r_2\ )^2 \qquad (4)$$

where L_{12} is the spreading coefficient of phase 1 (the adhesive) on phase 2 (the adherent). r_2 is the surface tension of phase 2. w_0 is the size of the unwetted interfacial void when L_{12}=0. Then, the interfacial fracture strength F can be give as [2]

$$F = (EG/w_0)^{1/2} /\ (\ 1 - L_{12}/r_2\ ) \qquad (5)$$

where E and G are the elastic modulus and fracture energy of the system. From equations (3), (4) and (5), one has

$$(F_i - F_0)/(F_i - F) = \exp\ (t/b) \qquad (6)$$

where F is the bond strength at time t, F_i that at infinite time, F_0 that at time zero, and b the retardation constant. Therefore, bond strength develops by first-order kinetics.

The retardation constant varies with temperature according to the Arrhenius relation[3]

$$b = B\ \exp(E_a/RT) \qquad (7)$$

where B is a constant. E_a is the activation energy for the adhesive bonding process. R is the gas constant and T is the absolute temperature. Combining equations (6) and (7) gives

$$\ln\ [(F_i - F_0)/(F_i - F)] = (t/B)\ \exp(-E_a/RT) \qquad (8)$$

which relates the adhesive bond strength F to the bonding time t and bonding temperature T. For short times, it simplifies to

$$F/F_i = (t/B)\ \exp(-E_a/RT) \qquad (9)$$

Thus, a plot of lnF versus 1/T should give a straight line for short times. From the slope, the activation energy E_a can be obtained for the system.

Results and Discussion

The results show that the peel force is constant, about 2.2 g/in, for heated roller temperature under 280°F. For the temperature equal or above 290°F, the peel force increases with the temperature. When temperature is above 302°F, relative strong bonding at layer 1/layer 2 interface let peel failure occur in release (layer 3). Also, a comparison of the peel force at two different applied pressure indicates that increasing pressure at the interface increases the peel force when heated roller temperature equal or above 290°F. From equation (2), the interface temperature T of layer 1/layer 2 can be estimated. The results are shown in Table 1.

Table 1. Estimated layer1/layer2 Interface Temperature From Heated Roller.

T_r ($^{\circ}$F)	T_r ($^{\circ}$C)	T ($^{\circ}$C)	$1/T \times 10^3$ ($^{\circ}$K)
290	143	96.98	2.70
295	146	98.81	2.69
300	149	100.64	2.68
302	150	101.25	2.67

Thus, when the heated roller temperature is or above 290°F(143°C), the corresponding interface temperature is or above 96°C, which is about the T_g of layer 1. As a result, the relatively strong peel strength likely corresponds to the onset of mobility of chain of layer 1 associated with its glass transition, which permits better wetting and diffusion.

Figure 2 plots of lnF vs. $1/T_i$ ($T_i \geq T_g$) for pressure 60 psi. According to equation (9), linear relations should be found. Clearly, the data show excellent agreement with the prediction. The straight lines are linear least squares fits. From the slopes of these linear relations, the activation energy E_a can be obtained for this system. The results are shown in Table 2.
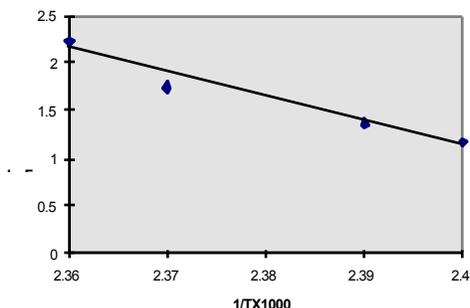
Figure 2. Plot of lnF vs. 1/T at 60 psi. The Straight Line is Linear Least Squares Fit.

Table 2. Estimated Activation Energy E_a.

Pressure (psi)	E_a (kcal/mole)
60	69
70	71

(B) Study of Release Strength

Results and Discussion

Figure 3 shows values of release strength as a function of the heated roller temperature T_r for two applied pressures, 60 psi and 70 psi. Each point in Figure 3 is an average value from four measurements. The standard deviation is under 15%, assuming a random selection from a normally distributed population. The data clearly show that release strength increases with the heated roller temperature. A comparison of the release strength at two different applied pressure indicates that increasing pressure also increases the release strength.

From equation (2), the temperature of release layer T_e can be estimated. The results are shown in Figure 4. Thus, when the heated roller temperature is or above 340°F(171°C), the estimated corresponding release layer temperature is or above 103°C, which is higher than 96°C, the T_g of layer 1. As a result, the fracture failure occurs in release. (Note that when layer 1/layer 2 interface temperature is above the T_g of layer 1, the corresponding interface strength increases dramatically).
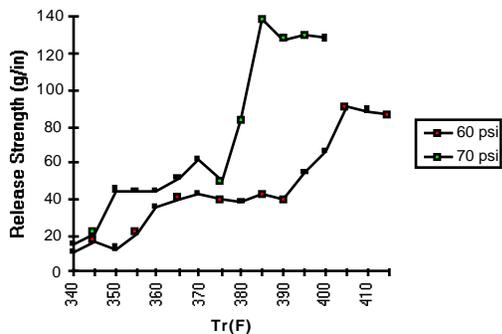

Figure 3. Release strength as a function of the heated roller temperature for two applied pressures at contact time 0.06 sec.
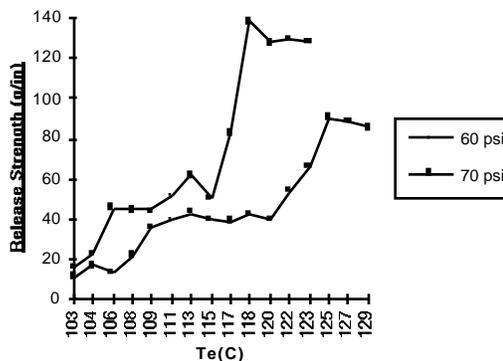

Figure 4. Release strength as a function of the estimated release layer temperature for two applied pressures at contact time 0.06 sec.

The effect of temperature on the release strength appears to illustrate a two-stage process. The release strength versus temperature plots in Figure 4 show two plateaus. We believe that has some significance for understanding the release fracture mechanism as function of temperature and pressure. Speculation could be drawn is that the first plateau may correspond to the attainment of complete wetting, and the second plateau to the attainment of equilibrium diffusion.

Conclusions

We investigated the development of peel force and release strength as a function of temperature and pressure at short times. A general agreement between the experimental data and a theoretical prediction suggests that a primary mechanism for adhesion development for layer 1 and layer 2 at short times is due to the establishment of interfacial molecular contact by wetting. The effect of temperature on the release strength appears to illustrate a two-stage process: the first plateau may correspond to the attainment of complete wetting, and the second plateau to the attainment of equilibrium diffusion.

Acknowledgments

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